REFERENCE

Hurricanes: The Greatest Storms on Earth

Introduction

Few things in nature can compare to the destructive force of a hurricane. Called the greatest storm on Earth, a hurricane is capable of annihilating coastal areas with sustained winds of 155 mph or higher and intense areas of rainfall and a storm surge. In fact, during its life cycle a hurricane can expend as much energy as 10,000 nuclear bombs!

The term hurricane is derived from Huracan, a god of evil recognized by the Tainos, an ancient aborigines Central American tribe. In other parts of the world, hurricanes are known by different names. In the western Pacific and China Sea area, hurricanes are known as typhoons, from the Cantonese tai-fung, meaning great wind. In Bangladesh, Pakistan, India, and Australia, they are known as cyclones, and finally, in the Philippines, they are known as baguios.

Hurricane Formation and Decay

Hurricanes form over tropical waters (between 8° and 20° latitude) in areas of high humidity, light winds, and warm sea surface temperatures (typically 26.5°C [80°F] or greater). These conditions usually prevail in the summer and early fall months of the tropical North Atlantic and North Pacific Oceans and for this reason, hurricane "season" in the northern hemisphere runs from June through November.

"SURFACE PRESSURES FALL AS WATER VAPOR CONDENSES AND RELEASES LATENT HEAT INTO AREAS WITHIN THE TROPICAL DISTURBANCE."

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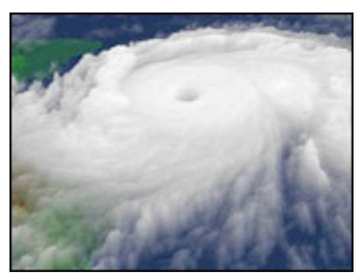
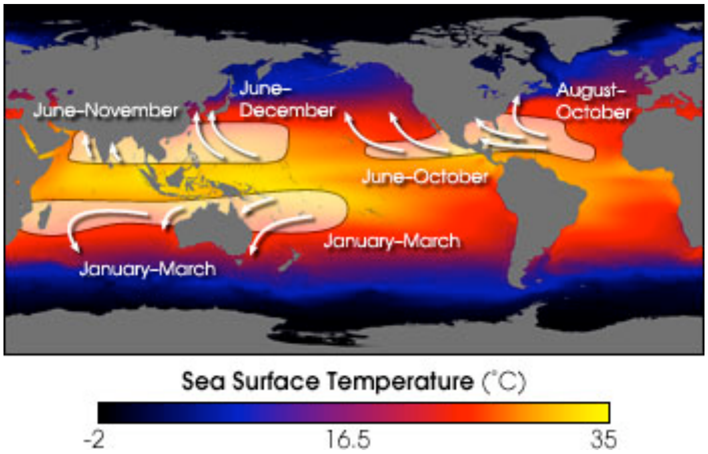
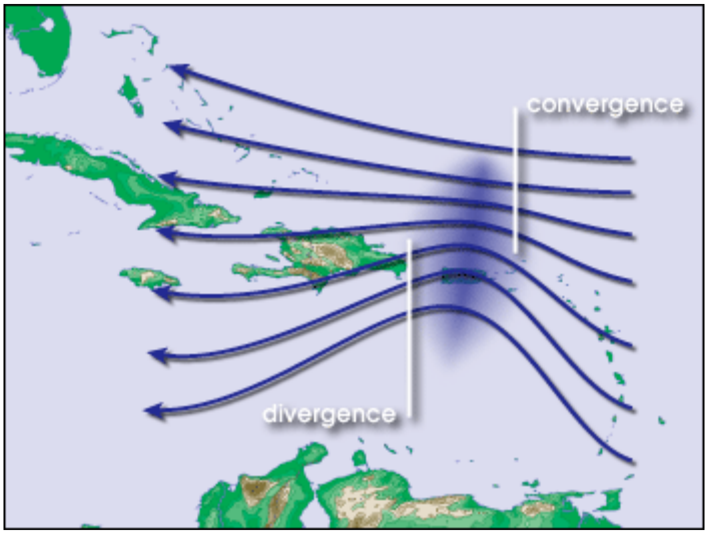


Hurricane Mitch, seen here in a three-dimensional perspective, was one of the most destructive storms of the 20th century. It soaked Nicaragua and Honduras in October 1998. (Image courtesy Visual Analysis Lab, NASA GSFC)



Hurricanes form in late summer and early fall when ocean waters are warmest. (Graphic by Robert Simmon, NASA GSFC)

The first sign of hurricane genesis (development) is the appearance of a cluster of thunderstorms over the tropical oceans, called a tropical disturbance. Tropical disturbances most commonly form in one of three different ways, all of which involve the convergence of surface winds. Near the equator, the easterly trade winds converge (come together) to trigger numerous thunderstorms in a region called the Intertropical Convergence Zone (ITCZ). Occasionally, a cluster of thunderstorms will break away from the ITCZ and become better organized. Another mechanism is the convergence of air that occurs along a mid-latitude frontal boundary that has made its way into the Gulf of Mexico or off the East Coast of Florida. The last mechanism is the easterly wave, a tropical disturbance that travels from east to west in the region of the tropical easterlies. Converging winds on the east side of the easterly wave trigger the development of thunderstorms. In fact, most Atlantic hurricanes can be traced to easterly waves that form over Western Africa.

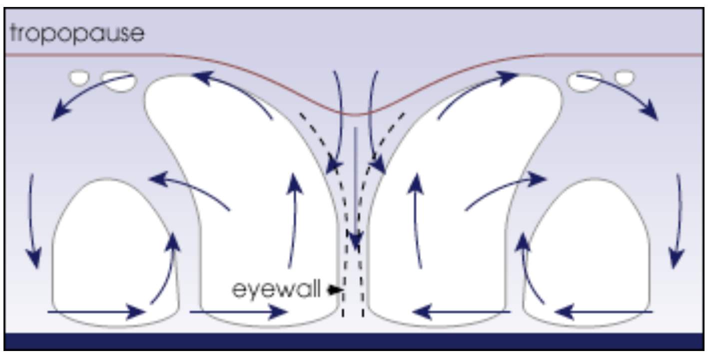


Waves in the trade winds—areas of converging winds that move along the same track as the prevailing wind—create instabilities in the atmosphere that may lead to the formation of hurricanes. (Graphic by Robert Simmon, NASA GSFC)

Given favorable conditions, the tropical disturbance can become better organized, indicated by falling surface pressures in the area around the storm and the development of a cyclonic circulation (counter-clockwise in the Northern Hemisphere). Surface pressures fall as water vapor condenses and releases latent heat into areas within the tropical disturbance. (Latent heat is the heat energy released or absorbed during the phase change of a substance—in this case, water vapor.) In response to the atmospheric heating, the surrounding air becomes less dense and begins to rise. As the warm air rises, it expands and cools triggering more condensation, the release of more latent heat, and a further increase in buoyancy, thus allowing more air to rise. A chain reaction (or feedback mechanism) is now in progress, as the rising temperatures in the center of the storm cause surface pressures to lower even more. Lower surface pressures encourage a more rapid inflow of air at the surface, more thunderstorms, more heat, lower surface pressure, stronger winds, and so on. If the storm is far enough from the equator (generally at least

8° of latitude), the Coriolis force will induce the converging winds into a counterclockwise circulation about the storm's area of lowest surface pressure.

Meanwhile, air pressures near the top of the storm, in response to the latent heat warming, begin to rise. In response to higher pressures aloft, air begins to flow outward (diverge) around the top of the center of the cyclone. Analogous to a chimney, this upper-level area of high pressure vents the tropical system, preventing the air converging at the surface from piling up around the center. If this were to occur, surface pressures would rise inside the storm and ultimately weaken, or even destroy it.



Hurricanes form when the energy released by the condensation of moisture in rising air causes a chain reaction. The air heats up, rising further, which leads to more condensation. The air flowing out of the top of this "chimney" drops towards the ground, forming powerful winds. (Graphic by Robert Simmon, NASA GSFC)

Once sustained wind speeds reach 37 km (23 miles) per hour, the tropical disturbance is called a tropical depression. As winds increase to 63 km (39 miles) per hour, the cyclone is called a tropical storm and receives a name, a tradition started with the use of World War II vintage code names such as Able, Baker, Charlie, etc. For a number of years beginning in 1953, female names were used exclusively, and then the alternation of male and female names began in the late 1970s. Finally, when wind speeds reach 119 km (74 miles) per hour, the storm is classified as a hurricane.

Even when the conditions are ripe for hurricane formation at the surface, the storm may not form if the atmospheric conditions aloft (5-10 km above the surface) are not favorable. For example, around the area of 20° latitude, the air aloft is often sinking, due to the presence of the sub-tropical high—a semi-permanent high pressure system in the subtropical regions that facilitates sinking air motions (subsidence). The sinking air warms and creates a temperature inversion (an extremely stable air layer in which temperature increases with altitude, the inverse of the usual temperature profile in the lower atmosphere) known as the trade wind inversion. This warm layer is very stable, making it difficult for air currents to rise and form thunderstorms and (eventually) hurricanes. In addition, strong upper-level winds tend to decapitate developing thunderstorms by dispersing the latent heat and cutting off the storm's source of fuel.

At the surface, hurricanes can diminish rather quickly given the right conditions. These conditions include: (1) the storm moving over cooler water that can't supply warm, moist tropical air; (2) the storm moving over land, again cutting of the source of warm, moist air; and finally (3) moving into an area where the large-scale flow aloft is not favorable for continued development or sustainment.

next: Hurricane Anatomy

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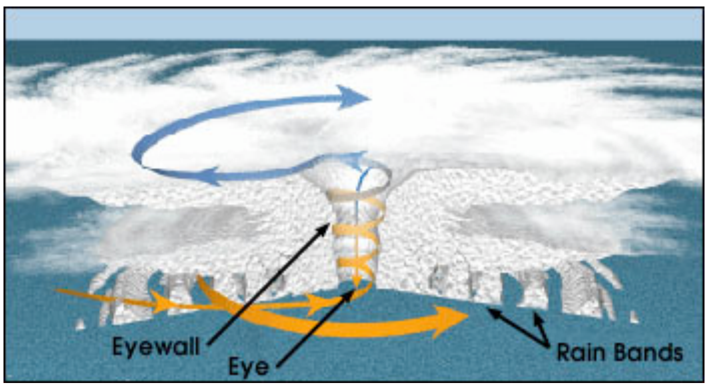
Hurricane Anatomy

During the stages of development described in the previous page, certain characteristics become more prominent as the hurricane increases in strength. At the center of the hurricane is a 10-to-65-km-diameter cloud free area of sinking air and light winds, called the eye. As air rises in the surrounding thunderstorms, some of it is

> "At the center of the hurricane is an area mostly free of clouds, sinking air, and light winds, called the eye."

forced towards the center, where it converges and sinks. As this air sinks, it compresses and warms to create an environment (mostly) free of clouds and precipitation. The eye is the calmest part of the storm because the strong surface winds converging towards the center never actually reach the exact center of the storm, but instead form a cylinder of relatively calm air. Like an ice skater whose body spins faster as their arms are drawn inward, air near the surface attempts to speed up as it spirals in towards the center of the hurricane (known as the Law of Conservation of Angular Momentum). Since the winds can't increase infinitely (a product of the Law of Conservation of Energy), they must stop short of reaching the center.



(Image courtesy NOAA)

Bordering the eye of a mature hurricane is the eye wall, a ring of tall thunderstorms that produce heavy rains and very strong winds. The most destructive section of the storm is in the eye wall on the side where the wind blows in the same direction as the storm's forward motion. For example, in a hurricane that is moving due west, the most intense winds would be found on the northern side of the storm, since the hurricane's winds are added to the storms forward motion.

Surrounding the eye wall are curved bands of clouds that trail away in a spiral fashion, suitably called spiraling rain bands. The rain bands are capable of producing heavy bursts of rain and

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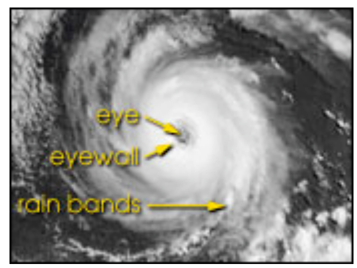

Hurricane Beatriz had a well-formed eye on July 12, 1999, while she was in the Pacific Ocean 800 miles off the coast of Mexico. (Image courtesy NOAA) wind, perhaps one-half or two-thirds the strength of those associated with the eye wall.

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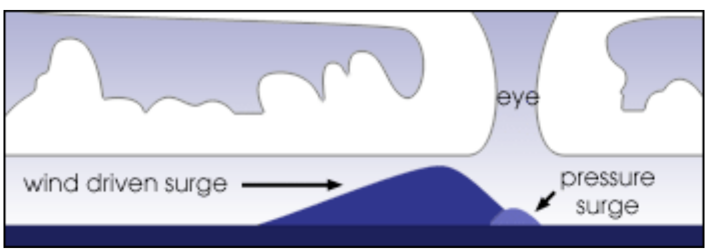
Storm Surge

As a hurricane moves closer to land, coastal communities begin to feel the effects of heavy rain, strong winds, and tornadoes. However, its most destructive weapon is the accompanying storm surge, a rise in the ocean levels of up to 10 meters (about 33 feet). As a hurricane approaches the coast, an 80-to-160-km-wide dome of ocean water sweeps over the coastline. Storm surges have demolished marinas, piers, boardwalks, houses, and other shoreline structures, while eroding beaches and washing out coastal roads and railroads. Strong onshore winds pushing the ocean surface ahead of the storm on the right side of the track (left in the Southern Hemisphere) is the primary cause of the storm surge. This wall of water is greatest when combined with the occurrence of an astronomical high tide.



(Graphic by Robert Simmon, NASA GSFC)

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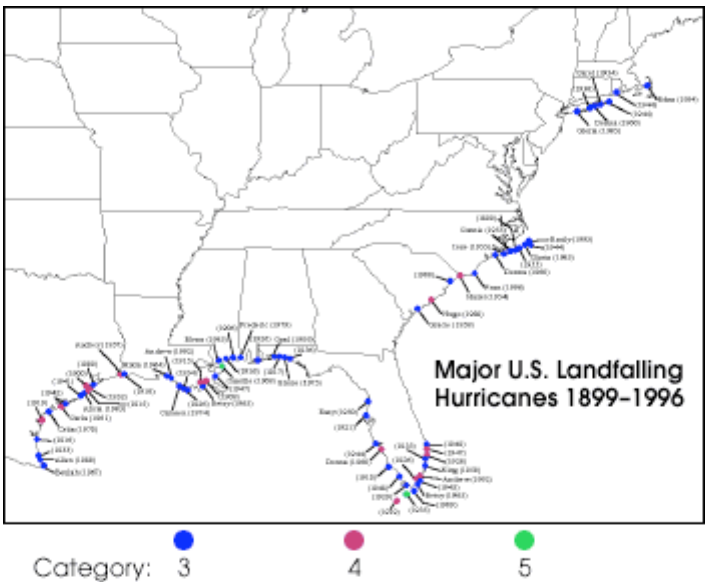
Hurricane Climatology

The number of hurricanes occurring annually on a global basis varies widely from ocean to ocean. Globally, about 80 tropical cyclones occur annually, one-third of which achieve hurricane status. The most active area is the western Pacific Ocean, which contains a wide expanse of warm ocean water. In contrast, the Atlantic Ocean averages about ten storms annually, of which six reach hurricane status. Compared to the Pacific Ocean, the Atlantic is a much smaller area, and therefore supports a smaller expanse of warm ocean water.



click to enlarge (Image courtesy NOAA)

Hurricane frequency can vary significantly from year to year. Scientists continue to investigate the interactions between hurricane frequency and El Niño. El Niño is a phenomenon where ocean surface temperatures become warmer than normal in the equatorial Pacific Ocean. In general, El Niño events are characterized by an increase in hurricane activity in the eastern Pacific and a decrease in activity in the Atlantic, Gulf of Mexico, and the Caribbean Sea. During El Niño years, the wind patterns are aligned in such a way that there is an increase in vertical wind shear over the Caribbean and Atlantic. The

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increased wind shear helps to prevent tropical disturbances from developing into hurricanes. Oppositely, in the eastern Pacific, wind patterns are altered in such a way that there is a reduction in wind shear in the atmosphere, contributing to more storms.

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The Saffir-Simpson Scale

In the early 1970's, a classification system was designed to quantify the level of damage and flooding expected from a hurricane. This system was conceived by Herbert Saffir, a consulting engineer, and Robert Simpson, then the director of the National Hurricane Center. Using a mix of structural engineering and meteorology, they constructed the Saffir-Simpson Hurricane Intensity Scale, or simply, the Saffir-Simpson Scale. Consisting of 5 categories (1 being the weakest and 5 being the strongest), the scale corresponds to a hurricane's central pressure, maximum sustained winds, and storm surge. Sustained wind speeds are the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Categories 3, 4, and 5 are considered as major (intense) hurricanes, capable of inflicting great damage and loss of life.

Scale Number	1	2	3	4	5
central pressure (mb)	> 980	965–979	945–964	920–944	< 920
wind speed (mi/hr)	74–95	96–110	111–130	131–155	> 155
storm surge (ft)	4–5	6–8	9–12	13–18	> 18
damage	minimal	moderate	extensive	extreme	catastrophic

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"Categories 3, 4, and 5 are considered major (intense) hurricanes on the Saffir-Simpson Scale."

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NASA Missions to Study Hurricanes

QuikSCAT

NASA's Quick Scatterometer (QuikSCAT) spacecraft was launched from Vandenberg Air Force Base, California on June 19, 1999. QuikScat carries the SeaWinds scatterometer, a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over the Earth's oceans.

In recent years, the ability to detect and track severe storms has been dramatically enhanced by the advent of weather satellites. Data from the SeaWinds scatterometer is augmenting traditional satellite images of clouds by providing direct measurements of surface winds to compare with the observed cloud patterns in an effort to better determine a hurricane's location, direction, structure, and strength. Specifically, these wind data are helping meteorologists to more accurately identify the extent of gale-force winds associated with a storm, while supplying inputs to numerical models that provide advanced warning of high waves and flooding.

"QuikScat and TRMM are allowing scientists to observe a hurricane's wind and rain before it makes landfall."

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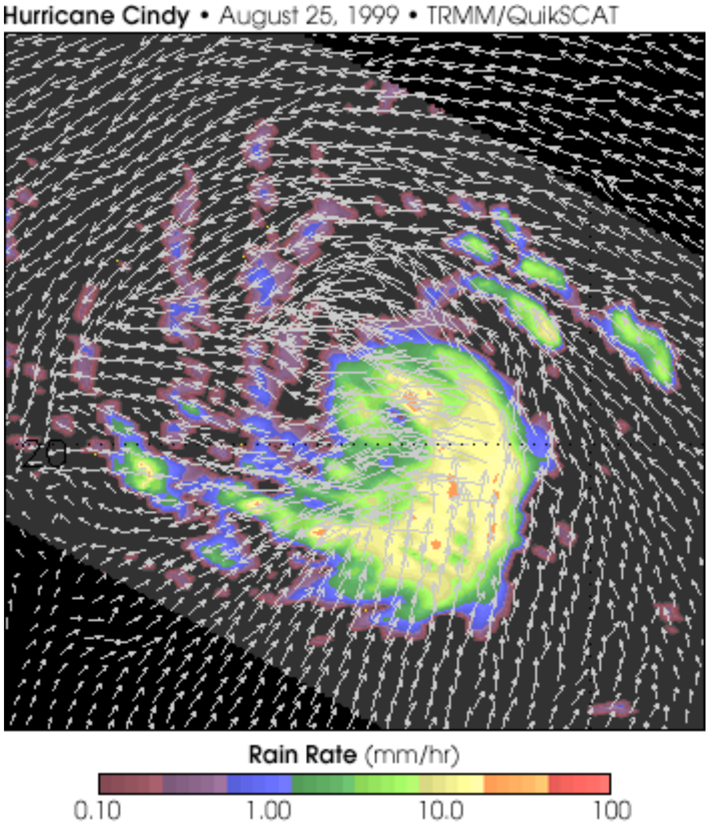

Scientists gained an unprecedented view of hurricanes with QuikSCAT and TRMM data. QuikSCAT measures wind (arrows) while TRMM measures rainfall (color). The two satellites observed Cindy on August 25, 2000. The storm reached category 4 strength, but never threatened land. (Image courtesy Seaflux, NASA/JPL)

TRMM

NASA's Tropical Rainfall Measuring Mission (TRMM), the first space mission dedicated to studying tropical and subtropical rainfall, was launched on November 27, 1997, from the Japanese Space Center in Tanegashima, Japan. TRMM carries a suite of advanced instruments that include the world's first spaceborne Precipitation Radar (PR), the TRMM Microwave Imager (TMI), a Visible and Infrared Scanner (VIRS), a Clouds and the Earth's Radiant Energy System (CERES), and a Lightning Imaging Sensor (LIS).

Scientists are using the Precipitation Radar and the TRMM Microwave Imager to peer inside the tropical thunderstorms associated with hurricanes in an attempt to understand which parts of a hurricane produce rainfall and why. In addition, TRMM data are being used to answer the question of how latent heat release affects global weather patterns.

Most importantly to people endangered by hurricanes, TRMM will add to the knowledge needed to improve computer-based weather modeling. With these data, meteorologists may be more able to precisely predict the path and intensity of these storms.

Together, QuikSCAT and TRMM are providing scientists with the opportunity to observe a hurricane's wind and rain before it makes landfall. The coincident measurements of surface wind and rain reveal the interplay between the hydrologic balances and energy exchanges within the storm. These variables are important in understanding the structure of the hurricane and predicting its path.

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